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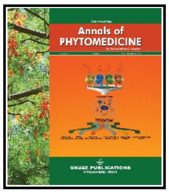

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Breeding approaches for the development of nutraceutical vegetables: A review

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Abstract

Nutraceuticals are the sustainable alternatives for prevention of number of human diseases. A vegetable with low calories possesses phytochemicals, antioxidants, minerals and vitamins, are the vital source of biologically active nutraceuticals. Some of the well studied phytonutraceuticals are lycopene, isoflavonoids, quercetin, glucosinolates sulforaphane, capsaicin, carotenoids, *etc*. Hence, it is important to precisely identify the plant-based bioactive chemicals that are essential for human nutrition. Through, both conventional and molecular breeding techniques, they should be investigated in order to create cultivars with superior nutritional characteristics. The breeding approaches such as traditional approaches and molecular breeding methods are well exploited for improving nutraceuticals vegetable properties. Biofortification is one of the latest and leading approaches for further enhancement of bioactive compounds in vegetables as evidenced by release of several biofortified varieties in sweet potato, cassava and greater yam from CTCRI, Thiruvananthapuram. Various aspects of nutraceutical crops such as germplasm resources evaluated, genes identified, breeding methods used and varieties developed in vegetable crops are reviewed in present paper. Further, the present review has been devoted towards better enhancing nutraceutical qualities of vegetables through biotechnological approaches.

1. Introduction

Malnutrition is one of the alarming problems particularly in the under-developed and developing countries. According to WHO guidelines from 2013, each person should consume 300 grammes of vegetables daily, including 125 grammes of leafy vegetables, 100 grammes of tubers and 75 grammes of other vegetables. Unfortunately, there is a shortfall in vegetable consumption of between 20 and 50 per cent. In India, around 15 per cent people are malnutritioned and vulnerable to health problems. Whereas, 38.40 per cent of the children are stunted and 35.70 per cent are underweight. Annually, India spends to the tune of $12 billion in GDP due to vitamin and mineral deficiencies (Yadav *et al*., 2017). Nutritional supplementation through dietary diversification, biofortification and eating habit of nutraceutical vegetables are viable options to combat this problem (Yadav *et al*., 2017). Vegetables are excellent source of vitamins and minerals (phosphorous, iodine and sodium), carbohydrates, proteins and fibres; hence, the vegetables are regarded as nutraceuticals, which can act as cheapest sources to overcome malnutrition in human beings and are the vehicles of ensuring nutritional security in India. Various nutraceuticals, *i.e.*, quercetin, glycosylates, folates, lycopene, alliin and allyl propyl disulfide of vegetable crops (Table 1) helps in curing of various human diseases. The breeding approaches such as traditional approaches and molecular breeding methods are available for improving nutraceuticals vegetable properties. Various aspects of nutraceuticals such as germplasm resources evaluated, genes identified, breeding methods used and varieties developed in vegetable crops are discussed in the present review.

2. Nutraceutical vegetables

The diversified, cost effective, highly nutritive vegetables are having greater importance in alleviating malnutrition. Vegetables are considered nutraceuticals because they contain phytochemicals in

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addition to vitamins and pro-vitamins. Almost every vegetable is enriched with one or the other nutraceutical compound. Various vegetable crops with their nutraceutical compounds are presented in the Table 2.

Table 1: Vegetable sources of important nutrients

Nutrients	
Cowpea, french bean, lima bean and pea	Protein
Brinjal, pointed gourd, snake gourd, sweet corn, bengal gram leaves, bitter gourd, sweet pepper, and chilli	Fat and oil
Vitamins	
Pumpkin, spinach and carrot	Vitamin A
Tomato, pea, garlic, onion and chilli	Vitamin B1
Drumstick, sweet pepper, cabbage and chilli	Vitamin C
Amaranthus, bitter gourd, pointed gourd and palak	Vitamin B5
Minerals	
Amaranthus, palak, and dolichos bean	Calcium
Drumstick, pea, lima, and taro leaves	Phosphorous
Palak, spinach, lettuce, bitter gourd and amaranth	Iron
Green onion, radish, Chinese cabbage and celery	Sodium
Okra, tomato, sweet pepper, carrot and garlic	Iodine
Lettuce, cabbage, spinach, cowpea, palak or beet leaf and french beans	Folic acid

Source: Gomathi *et al.* (2017)

Table 2: Vegetable crops with nutraceuticals compounds

Botanical name	**Nutraceuticals**
Abelmoschus esculentus	Quercetin and derivatives of flavonol
Allium cepa	Resveratrol
Allium cepa, Allium sativum	Quercetin, Allylpropyl disulfide, Alliin and Methiin
Amaranthus spp. *spinaceaoleracea, Trigonella foenum-graecum*	Vitamin E, C and Folates
Apium graveolens, Brassica oleracea var. *italica*	Luteolin and Apigenin
Asparagus officinalis, Capsicum annuum	Rutin
Beta vulgaris	Ferulic Acid and Betanin
Brassica oleracea var. *italica*	Glucobrassicin, Gluconasturtiin and Progoitrin
Brassica rapa, Brassica napus	Glucoerucin and Glucoraphanin
Capsicum annuum	Capsaicin
Cichorium intybus var. *foliosum, Armoracia rusticana*	Myricetin, Fisetin and Kaempferol
Cynara cardunculus var. *scolymus*	Silymarin
Daucus carota, Cucurbita moschata, Cucumis melo var. *cantalupensis*	Vitamin A
Glycine max	Genistein, Daidzein and Nattokinase
Ipomoea batatas	Chlorgenic acid and Anthocyanin
Pisum sativum, Vigna unguiculata, Cyamopsis tetragonoloba	Isoflavonoids, Quercetin, Glucosinolates sulforaphane, Capsaicin
Solanum lycopersicum, Capsicum spp.*, Solanum melongena*	Lycopene
Solanum melongena	Caffeic acid, chlorgenic acid and nasunin
Solanum tuberosum	Chlorgenic acid and lysine
Spinacea oleracea	Patuletin and spinacetin
Vegetable Brassicas spp.	Glucosinolates, sulforaphane, vitamin C, luteolin and apigenin
Musa paradisiaca (Vegetable type)	Benzoic and chlorogenic acid, citric and ferulic acid, oleanolic and salicylic acid

3. Breeding history and genetic resources

Breeding activities aiming at improved micronutrient content and composition began in the 1940s and 1950's, with research narrating the inheritance and development of tomato breeding lines high in pro-vitamin A, carotenoids and vitamin C. Similar for development of darker orange and consequently high pro-vitamin A, carrots began in the 1960s. The genetic improvement protocols to increase levels of specific micronutrient are also pursued in vegetables. The calcium, zinc and iron across a range of Andean potato cultivars was reported (Andre *et al*., 2007). The use of molecular or conventional breeding has led to the development of micronutrients enriched varieties like beta-carotene enhanced sweet potatoes, carrot and potato. Pavithra *et al*. (2014) reported tomato lines rich in zinc content. The elite germplasm line with high zinc content may be used to prospect candidate gene for improving nutritional value.

4. Germplasm for nutritional traits

Use of germplasm is always an immediate source of nutraceuticals. Screening of germplasm through lab test, visual observations and organoleptic scoring are useful to identify donar sources, which is a pre-requisite for any breeding programme. Cultivated varieties, genetically modified lines and wild species and mutant genotypes are identified donars with nutraceutical compounds by various research groups (Ruggieri *et al*., 2014; Al-Said *et al*., 2014; Jourdan *et al*., 2015; Sarpras *et al*., 2016; Kumari *et al*., 2018).

Table 3: Donors with bioactive compounds in various vegetable crops

Bioactive compound	Source	Crop improved
Ascorbic acid	Double rich cultivar of *S. pimpinellifolium*	Tomato
Beta carotene	Caro Red and Crimson	
Anthocyanin	*S. atroviolacium* (atv) and *S. chilense* from *S. cheesmaniae*	
Phenolics	IL6-2, IL7-2 of *S. pennellii*	
Protein	*S. vernei* and *S. phureja*	Potato
Carotene	Douxed Alger	Pepper
Ascorbic acid	IC 119262 (CA2), Bayadaggikaddi of *C. annuum*	
Capsanthin	KTPL-19	Paprika
Protein	Kinnauri, Laxton and GC 195	Pea
Vitamin A	Pusa Meghali	Carrot
Carotene	Golden Delicious	Pumpkin
Beta carotene	Xishuangbanna gourd developed from *C. sativus* var. *xishuangbananesis*	Cucumber
Vitamin A	UMUCASS 44, UMUCASS 45 and UMUCASS 46	Cassava
Ascorbic acid	Honey dew 32	Muskmelon
Flavons (Naringenin chalcone)	Canary yellow	
Glucosinolates	*Brassica villosa*	Broccoli
Protein	*Momordica dioica*	Spine gourd
Lycopene	*M. chochinchinenesis*	

5. Genes for bioactive compounds identified

Being informed with the importance of quality traits in nutraceuticals, several genes govering those traits are mapped using molecular markers. '*Or*' mutant gene in cauliflower (Li *et al*., 2003), Aft, Abg gene in tomato (Giorgiev, 1972; Rick *et al*., 1994), PSY gene (Santos *et al*., 2005) and 13QTL in carrot (Trebbi *et al*., 2005) and fap 10.1 gene in brinjal (De Jong *et al*., 2009) are some of the examples (Table 4) where genes are successfully indentified and widely used in transgenic varietal development.

Table 4: Genes identified for bioactive compounds in vegetable crops

Nutrient enrichment	Vegetable crop	Gene identified
b-carotene	Potato	*Or*
Phytoene		Dxs
Protein		*AmA1*
b-carotene		Crt B
b-carotene	Tomato	B
High flavanoids		Chi-a
Carotene		Phytoene synthase (Psy-1)
Lutein		cry-2
Lycopene		ySAMdc; spe-2
Folate		GCH1
Kaempferol		LC and C1
Anthocyanin		Aft, Abg
Tocopherols		Hmgr-1
Anthocyanin	Sweet potato	IbMYB1
High protein		Asp-1
Folate	Lettuce	Gch1
Iron		Pfe
Ascorbate		Gul oxidase
Anthocyanin	Red cabbage	MYB
b-carotene	Cauliflower	*Or*
Anthocyanin	Purple cauliflower	*Pr*
b-carotene	Cucumber	*Ore*

6. Breeding approaches

Many plant breeding approaches are applied for the development of nutraceuticals enriched crops. Screening and selection of nutraceutical enriched genotypes, back cross and mutation breeding among traditional approaches, whereas, marker assisted selection (MAS) and transgenic crops among the molecular approaches are the potential tools to harness the nutraceutical compounds of crops.

6.1 Traditional breeding approaches

6.1.1 Biofortification

Biofortification is one of breeding process of crops with the aim of enhancing both their mineral density and bioavailability. Mineral biofortification is executed as the growing phase of agricultural crops (Dwivedi *et al*., 2012). There are several reports on biofortification of Zn, Ca, and Se, as they are considered as limiting minerals in plant-based diets (Kim *et al*., 2006). In sweet potato, the goal of the biofortification schemes is the substitution of orange-fleshed, high pro-vitamin 'A' plants for white-fleshed, low pro-vitamin 'A' cultivars (Gomathi *et al*., 2017). Numerous nutraceutical-rich biofortified cultivars have been made available by CTCRI, Trivandrum. Sree Kanaka, Bhu Krishna and Bhu Sona are biofortified varieties of sweet potato, whereas Sree Visakham is a biofortified variety of tapioca (Table 5, Figure1). The orange fleshed sweet potatoes when boiled also retain 80% of the initial concentration of beta carotene (van Jaarsveld *et al*., 2006). So, the bioavailability of beta carotene is good to meet the demands of human beings.

Table 5: Some of the developed biofortified varieties with their characters

Crop	Biofortified variety	Breeding method used	Nutraceutical compound	Other characters	Reference
Sweet potato	Sree Kanaka	Pure line selection	Orange fleshed with β-carotene content (8.8-10.0 mg/100 g)	Early maturing variety (75-85 days)	CTCRI
	Bhu Sona	Pure line selection	Orange fleshed sweet potato with carotene (13.2-14.4 mg/100 g)	It contains β-carotene content is high (14.0 mg/100 g) as compared to 2.0-3.0 mg/100 g β- carotene in already released varieties. It gives an average tuber yield of 19.8 t/ha with 20% starch, dry matter 27.0-29.0%. It possess 2.0-2.4% total sugar	CTCRI
	Bhu Krishna	Pure line selection	Flesh is purple; anthocyanin content varies from 85-90 mg/100 g	Tuber yield: 18.0 t/ha; Dry matter: 24.0-25.5%; Starch: 19.5%; Total sugar: 1.9-2.2%	CTCRI
	Bhu Kanti	Pure line selection	Orange fleshed variety	Beta carotene (6.5 mg/100 g)	CTCRI
	Bhu Ja	Pure line selection	Orange fleshed variety	Beta carotene content (5.5-6.4 mg/100 g)	CTCRI
Greater yam	Sree Neelima	Pure line selection	Purple fleshed variety	Anthocyanin (15 mg/100g)	CTCRI
	Da 340	Pure line selection	Purple flesh genotype	Anthocyanin (37.69 ±2.21 mg/100 g)	CTCRI
Cassava	17S325	Pure line selection	Yellow flesh genotype	Higher carotene (6.01 mg/100 g)	CTCRI
Cauliflower	Pusa Beta Kesari 1	Pure line selection	contains high b-carotene (8.0-10.0 ppm)	It's the first biofortified cauliflower	ICAR-IARI
Radish	Pusa Jamuni		High anthocyanins and ascorbate	It is the first purple fleshed radish variety	IARI
	Pusa Gulabi		High total carotenoids, anthocyanins and optimal ascorbic acid	The first entire pink fleshed radish variety	IARI
Potato	MS/8-1565 (Kufri Neelkanth)	Pure line selection	It produces purple coloured, ovoid, uniform tubers with shallow eyes and yellow flesh and higher amounts of anti-oxidants	It is main season table potato variety having field resistance to late blight	CPRI

6.1.2 Hybridization followed by pedigree

This is one of the widely used breeding approaches for developing nutraceutical vegetable crops. For enhancing lycopene and anthocyanin, the mutant with dg or hp-2dg genes and the genotype with Aft gene were used in pyramiding of both the coloured compounds in tomato. In this breeding program, Alisa Craig (Aft Aft) and BCT-115 (dg dg) crossed and selfed twice and subsequently selection was made to identify pure AftAft dgdg genotype. The recently developed tomato variety "Purple tomato" was found to have both high anthocyanin (20.73 mg/100 g FW) and lycopene (6.13 mg/100 g FW) together.

6.1.3 Selection

It is one of the easiest breeding principles for release of varieties from germplasm and or segregating populations. Several nutraceutical vegetables were developed and released using selections.

Carrot: Pusa Rudhira has been released with higher levels of carotenoid (7.41 mg) and phenols (45.15 mg per 100 g). Pusa Asita is a self-colored core variety with long black roots.

Radish: ICAR- IARI has released several pink and purple fleshed radish varieties. Pusa Gulabi is first pink fleshed radish variety. It is rich in total carotenoids, anthocyanin and ascorbic acid. Pusa Jamuni is the first purple fleshed nutritionally rich with anthocyanin and ascorbic acid.

Brinjal: 'Pusa Safed Baigan 1' has been released in 2018 by IARI. It has high total phenol content and high antioxidant activity.

Carrot: Single dominant gene (*P1*) is responsible for anthocyanin accumulation in carrot roots. Due to the presence of anthocyanin, solid purple carrots, among other purple carrot kinds, are known as black carrots. The black carrot variety, Pusa Asita contains 300-350 mg of anthocyanin per 100 g fresh weight. Different pigments are combined to create multicoloured carrot types, such as purple orange (anthocyanins + beta-carotene), purple white (anthocyanins + lutein), and purple red (anthocyanins + lycopene). It offers possible anticancer properties. According to Selvakumar and his team's research (2016), the purple-orange-red cultivar has lycopene and carotenes of 62 ppm and 40 ppm, respectively.

Radish: Purple/pink pigmentation in radish is due topresence of anthocyanin. At IARI, New Delhi, several multi-colored radish cultivars such as Pusa Jamuni (Purple), Pusa Gulabi (Pink), Pusa Hriday (Pink), Pusa Sagarika (purple) and Kashi Lohit (Red colour) are developed.

		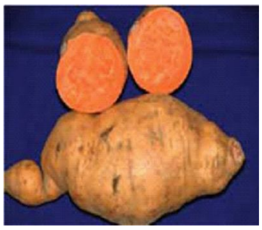	
Bhu Krishna (Sweet potato)	Bhu Kanti (Sweet potato)	Bhu Sona (Sweet potato)	Sree Neelima (Greater Yam)
			
Pusa Beta Kesari (Cauliflower)	Pusa Jamuni (Radish)	Pusa Gulabi (Radish)	Pusa Ashita (Black carrot)
			
MS/8-1565 (Kufri Neelkanth) Potato	Pusa Kulfi (yellow carrot)	Pusa Rudhira (red carrot)	Pusa Meghali (orange carrot)

Figure 1: Biofortified varieties in vegetables developed in India.

6.1.4 Mutation breeding

Mutations are the ultimate source of biological variation. In self-pollinated (SP) crops, mutations are well applied; while in cross pollinated crops, mutation application is more difficult. Sapir *et al.* (2008) reported high *pigment 1* (*hp-1*) mutation identified to increase flavanoids content in tomato fruits.

6.1.5 Polyploidy breeding

Application of polyploidy breeding in developing vegetable crops is well established. Tetraploids in watermelon, radish and pumpkin are highly productive and improved quality. Tetraploid muskmelon with enhanced vitamin C than those in the diploid fruit IS developed (Zhang *et al*. 2010).

6.1.6 Haploidy breeding

Haploid development is the rapid route to produce pure lines. There are some investigations for improvement of *Brassica* for nutraceutical species. There are very few successful double haploid protocols in this direction of nutraceutical vegetables crops.

6.2 Molecular breeding approaches

6.2.1 Molecular markers and marker assisted selection

Molecular markers are employed to study genetic linkage with genes encoding for high neutraceuticals including bioactive compounds. Many researches have brought into the limelight the genetic resources of nutraceuticals. Marker assisted backcross breeding, MAB successful to incorporate genes or QTL in potato, tomato and cucumber, *etc*. The dominant gene anthocyanin fruit (Aft) was introgressed into domesticated tomato plants by cross with *S. chilense* and the gene aubergine (*Abg*) from *Solanum lycopersicoides*. The anthocyanin pigmentation gene atroviolacea (*atv*), which upregulate the anthocycnin production was obtained from the interspecific cross with *Solanum cheesmaniae*. The gene for capsanthin-capsorubin synthase (CCs) was identified as a candidate gene for the *y* locus. Anthocyanin accumulation in the carrot is conditioned by the P1 locus, which is being dominant. Three genes, encoding phytoene synthase (CrtB), phytonene desaturase (Crt1) and lycopene beta–cylase (CrtY) from *Erwinia* were introduced in potato to develop beta carotene. Transgenic tomato enriched carotenoid content with the bacterial carotenoid gene (*crtl*) encoding the enzyme phytoene desaturase, which converts phytoene into lycopene (Romer *et al*., 2000). Diretto *et al*. (2006) silenced the first step in the b-epsilon branch of carotenoid biosynthesis, lycopene epsilon cyclase (LCY-e) in potato which led to the carotenoids production up to 14-fold more b-carotene.Three sets of transgenic onion plants with antisense alliinase gene constructs were produced (Eady *et al*., 2008). Transgenic hybrid onion seed from these transgenic lines were developed by crossing a nontransgeneic OPV line with a transgenic parental plant carrying a single transgene in the hemizygous state.

Ripley and Roslinsky (2005) identified an ISSR Marker for 2 propenyl glucosinolate content in *Brassica*. Bin 3-C has been identified as a single gene mutation *r* yellow flesh in tomato (Fray *et al*., 1993). The AB-QTL strategy was used in tomato and pepper. Quantitative trait loci (QTL) associated with carotenoids and tomato fruit colour using introgression populations of *S. pennellii*, *S. peruvianum* and *S. habrochaites* was presented (Berancchi *et al*., 1998). Cervantes-Flores *et al*. (2010) reported a QTL for starch content and b-carotene content of sweet potato. Ripley and Roslinsky, (2005) identified ISSRs linked for 2- propenly glucosinolate in Brassica. Liu *et al.* (2003) used candidate gene approach to link carotenoid biosynthesis to QTLs, which are responsible for the tomato red fruit colour.

6.2.2 Genetic engineering

Genetic modification techniques were used in several vegetable crops for improving their nutritional status and reducing anti-nutritional factors. Transgenic vegetables can be also used for vaccine delivery. Consumers could benefit further from eating more nutritious transgenic vegetables, *e.g*., an increase of crop carotenoids by metabolic sink manipulation through genetic engineering appears feasible in some vegetables. Genetically engineering carrots containing increase Ca levels may boost Ca uptake, thereby reducing the incidence of Ca deficiencies such as osteoporosis. Fortified transgenic lettuce with zinc will overcome the deficiency of this micronutrient that severely impairs organ function. Folates deficiency, which is regarded as a global health problem, can also be overcome with transgenic tomatoes with folate levels that provide a complete adult daily requirement. Transgenic lettuce with improved tocopherol and resveratrol composition may prevent coronary disease and arteriosclerosis and can contribute to cancer chemo-preventative activity. Food safety and health benefits can also be enhanced through transgenic approaches, *e.g*., rural African resource-poor consumers will benefit eating cyanide-free cultivars of cassava. Biotechnology-derived vegetable crops will succeed, if clear advantages and safety measures are demonstrated to both growers and consumers. Some of the successful achievements of genetic engineering in nutraceutical vegetable crops are as follows:

Golden tomato

The World Vegetable Centre has developed beta-carotene rich tomatoes which provide 3 to 6 times as much vitamin A as normal tomatoes. The high beta carotene content results in orange-fleshed fruit. A single tomato provides a person's daily vitamin A needs. WVC named it as AVTO 0102 (Figure 2); it is an early maturing variety with good heat tolerance, suited to hot-wet conditions.

Figure 2: Golden tomato developed by World Vegetable Centre, Taiwan and in cultivation.

Purple fleshed sweet potato

Anthocyanin rich purple fleshed transgenic sweet potato cultivar referred to as IbOr plants with over expressing IbOr-Insunder, cauliflower mosaic virus (CaMV) 35S promoter. The new variety has enhanced carotenoid levels (upto 7-fold) in their storage roots in comparision of wild type plants.

Purple cauliflower

The unique purple (*Pr*) gene mutation in cauliflower led to the accumulation of anthocyanin imparting the intense purple color to curds and a few other tissues of cauliflower. PrD-expressing transgenic cauliflower plants replicated the mutant phenotype. A subset of anthocyanin structural genes are activated by up-regulating Pr, resulting in ectopic accumulation of pigments in the purple cauliflower (Chiu *et al*., 2010).

Orange cauliflower

'*Or*'is a semi-dominant gene. It confers the accumulation of high levels of b-carotene imparting orange to tissues. There is variation in the intensity of colour. While plants with the homozygous *Or* gene have little curds and a bright orange hue, those with the heterozygous gene have curds that are less pigmented and are of average size (Li and Garvin, 2003).

Introgression "*Pr*"and "*Or*" gene in to vegetable crops at IARI

Two cultivars, namely; Pusa Snowball K1 and Pusa Snowball K25 were developed at IARI, New Delhi through introgression of two genes, a-carotene (*Or*gene) and anthocyanin (*Pr* gene) through marker-assisted backcross (MAB) selection.

In the similar fashion, an improved variety, S831 in cabbage and another variety, Pusa Broccoli KTS 1 in broccoli were developed through MAB of a-carotene rich '*Or*' gene. Indian cauliflower variety "Pusa purple cauliflower (KTCPF-1) having intense purple curd colour was developed *via* introgression of '*Pr*' gene. It possesses coloration deep into the curd bract; the mean anthocyanin amount per 100 g edible part was 43.7 mg. IARI, New Delhi, has introduced Pusa Purple Broccoli, which has a vibrant purple head colour. Chinese cabbage, cucumbers, and melons have all been found to have significant levels of a-carotene buildup (Yang *et al*., 1992).

Protein rich potato

A new protein packed genetically modified (GM) potato variety named as 'Protato' was developed. It contains 60% additional protein content than a wild-type potato with increased amount of amino acids. The *AmA1* (Amaranth Albumin 1) gene was isolated from grain amaranthus (*A. hypochondriacus*) and introgressed into normal potato. The protato has 7-20 per cent biomass extra to the wild potato (Chakraborty *et al*., 2010). The gene *AmA1* encodes a non-allergenic protein. Sugar-enriched potatoes discolour while cooking and lose some of their appeal to customers. Low-sugar potato plants that are genetically modified and chips prepared from such potatoes are lighter in colour and attractive (Navratil *et al*., 1998).

Figure 3: Purple tomato in fresh market.

Orange cucumber

XIS gourd is developed by the introgression of gene (s) controlling a-carotene into cultivated cucumber (lack of a-carotene) from Xishuangbanna gourd (possessing b-carotene). Its mature fruit has orangecolored endocarp/mesocarp with 700 mg b-carotene per 100 g fresh weight. This gourd is compatible to cross with traditional cucumber, can be used as donor for b-carotene improvement (Bo, 2012).

Anthocyanin rich tomato

Anthocyanins are pigments to impart red, purple and blue to their flowers and fruits (Figure 3). The development of the anthocyanin-rich tomato involved the interspecific cross of *S. chilense* and *Aft* gene into domesticated tomato plants. *Aft* is a dominant gene.

High glucosinolate F_1 broccoli

The broccoli has anti-carcinogenic activity due to activity of the isothiocyanates iberin and sulforaphane derived glucosinolates that present in the florets of broccoli. Faulkner *et al.* (1998) crossed broccoli with its wild relative (*B. villosa*), which had more 3-methylthio propyl glucosinolate than broccoli. The F_1 hybrids were reported with high levels of 4-methylsulphinylbutyl 4-MSB, had ability to induce quinine reductasein cell cultures.

Folates rich tomato

Transgenic tomatoes were developed by engineering fruit specific over expression of GTP cyclohydrolase I. Transgenic tomato ripened fruits are 25 fold rich in folate than controls (Diaz de la Garza *et al.*, 2004).

Miraculin rich vegetables

For reduction of bitterness in lettuce, the gene responsible for sweetness and taste modifying protein called miraculin was cloned from the pulp of berries of *Richadella dulcifica* (*Sun et al.*, 2006). Expression of this gene in transgenic lettuce plants led to sweet enhancing protein and reduced bitterness.

7. Conclusion

Owing to their protective effects against degenerative diseases, the vegetables are often called as 'protected foods'. Bioactive compounds such as anthocyanin, isoflavonoids, quercetin, betalins, lycopene, glucosinolates sulforaphane, carotenoids, chlorophylls and capsaicin are present in many vegetable crops and are commonly called as nutraceuticals. Screening of various sources of vegetable crops such as germplasm and other breeding lines resulted in identification of several bioactive compounds. The genes conditioning those quality traits are also discovered using several molecular approaches. To breed the new nutraceutical varieties of vegetable crops, conventional strategies such as selection, back cross and hybridization followed by pedigree have been attempted and some varieties are released for commercial cultivation as well. Advent of molecular markers enhanced the efficiency of breeding through MAS, genetic engineering, genome sequencing, which played a notable role in nutraceutical rich vegetable cultivars. Biofortification is of recent addition for enriching the vegetable crops with nutraceutical compounds. CTCRI, Thiruvananthapuram developed and released several biofortified varieties in sweet potato, cassava and greater yam for field cultivation. Genetically engineered nutraceutical vegetable crops have lion share in this area. However, genetic engineering is not a silver bullet for attaining the nutritional quality and health benefits as well. However, coupled with traditional breeding, it will be a powerful tool for making the availability of vegetables better with bioactive compounds in future.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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